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Nearly Zero Energy Ports: A necessity or a green upgrade?

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Abstract. Ports are situated in susceptible, to climate change, areas. The continuous technological advances on the global market and the growth of the trade activities are forcing ports to find new ways to be both competitive and harmonize with sustainable development's "legislation". Specifically, this actually means to practically evaluate all the possible actions and the mean which can be utilized in order to achieve their optimization and greenification. The main objective of this paper is to investigate, analyse and evaluate, through the proposed methodology, various energy-related data of the port of Rethymno and propose a hypothetical model to achieve the near Zero Energy Port (nZEP) concept and the criteria that have to be fulfilled in order to accomplish such an innovative purpose. The methodology to assess a port into the nZEP's concept is presented, including various crucial guidelines and criteria to define a port as nZEP. Last but not least, the research outcomes specify that there are some curtain gaps and opportunities. Thus, this paper establishes an educational and innovative handbook about an initial attempt to greenify a Mediterranean port and adapt it to nZEP's concept, utilizing good and essential practices and interventions/implementations in order to achieve this intention.

1. Introduction

The European Commission (EC) defined the energy priorities till 2050 and set the priority actions to tackle the challenges of saving energy, accomplishing a market with competitive prices and secure supplies, to address climate change and EU strongly encourages the environmental performance of services and products. [1]–[3]. Ports are obliged to comply with even stricter monitoring and social necessities regarding environmental protection and sustainability [4]–[6].

Due to the growing consciousness regarding sustainability into ports, gradually more and more knowledge and experience are mandatory in order to decrease the effect of port activities on climate change, as well as the impact of port infrastructures on the natural habitats (ecosystems) and national markets. [7] Some recent data on global energy consumption and carbon emissions appear to support the claim that we may be in the midst of an energy transition. The rapid and continuing growth of total energy consumption – which relates to continuing economic growth – makes it so that removing an energy source like fossil fuels is very difficult, even when the production of other energy sources is growing.

Therefore, challenging the forces that push for relentless economic growth may be necessary to change the historic pattern of energy additions without transition. Since the fossil fuel industry has a vested interest in maintaining growth in fossil fuel consumption and has been active in resisting a fundamental energy transition (including promoting the climate change denial movement), serious



progress to a sustainable future cannot be achieved without confronting the power of this industry in particular. [8]

Environmental aspects also should be considered as a competitive and necessary benefit in the future in order to appeal to probable transaction allies and possible stockholders. As such, port authorities should design arrangements to become nearly Zero Energy Ports (nZEP) in the long-term. While this topic is vital, the current research work needs to be expanded and to be further investigated. In cases of ports planning or certain suburb design, where preliminary planning decisions must be taken, some fixed parameters and their relationship with the microclimate are essential to be taken into consideration. [9]

On the other hand, both sea vessels, means of transport and means of cargo/logistics used nearby, are the main source of pollution and noise of port infrastructures [10], [11]. Ports worldwide are responsible for significant social and environmental costs resulting from Greenhouse Gas (GHG) emissions due to their operation [12]. As a result, many port executives have started the implementation of solutions in order to reduce transport costs and possible dilemmas (dead-end situations). Such actions include both internal measures such as formulating a number of financial incentives and infrastructural facilities to reduce GHG emissions by ships and transport vehicles, as well as initiatives aimed at the modal shift. [13]

There is significant potential for sustainable technology solutions and implementation of them into ports. The fact that Greece is a naval-related country enhances the prospect of nZEP and makes it a necessity towards a sustainable future. In order to enhance more the prospect of nZEP, it is indicative that there are more than 3,000 ports in Europe and more than 7,500 ports, worldwide. [14]. Ports worldwide set their environmental priorities each year and these priorities for the year 2018 are presented in Figure 1. [15], [16]



Figure 1. Top 10 environmental priorities of European ports for 2018 [15]

Therefore, there is a certain number of challenges that ports are facing, such as [16], [17]

- Energy Conservation
- Air Quality
- Noise levels
- Water Conservation
- Indoor Environmental Quality
- Materials & Resources Conservation
- Dredging & Disposal of dredged materials
- Storage, transport, and management of hazardous substances
- Ballast water control
- Habitat restoration

In parallel, there are critical bottlenecks associated with nZEP development, particularly in developing countries, such as:

- Several ports lack financial support and their management is based on old-fashioned techniques due to their age;
- Most port authorities allocate limited resources to conduct systematic and comprehensive nZEP planning and design;
- The incomplete evaluation method in order to become nZEP, which could be socially accepted and environmentally friendly;

The main goal of this research work, as a continuity of a previous one, is the inquiry of all the feasible solutions for an nZEP development in Rethymno for the year 2030. Both current and future needs and perspectives, using statistical analysis methods, are taken into account in order to properly set up and design this specific nearly Energy Zero Port. A great variety of vital factors concerning the financial feature (decreasing the operating costs), environmental conditions (diminishing pollutants coming from GHG emissions of the port and the old town around it) as well as accomplishing social acceptance and safety, were taken under consideration. Consequently, bearing in mind all the aforementioned, the suggested techniques and technologies will be feasible, sustainable and will have a positive impact on the surroundings of the port both financially and socially.

2. Methodology

The first thing done was to create a typology for ports in order to be able to sort each case study into a category. Ports can be grouped based on the following determinants:

- number of passengers
- number of ships
- actual size/type of ships (i.e. cruise, cargo, transportation, etc.)
- region (in most cases, the port town)
- services

So, this typology was based on crucial characteristics of each port and is shown in Table 1.

Table 1. Port categories

Local ports	National ports	International ports
Ports that cover the needs of an island (from/to) Small sized	Ports that cover the needs of a country Medium sized	Ports that cover the international needs of a country Large sized
They do not serve cruise ships, do not serve logistics	They do serve some cruise ships, they do serve small logistics	They do serve cruise ships, they do serve logistics

After reviewing the selected available literature and creating this specific typology, the Rethymno's port was selected as a case study due to its services which rank it as a small to medium port. Another crucial aspect for the selection of this port was that most ports in Greece are of this type and, more importantly, because the research team was able to obtain the required information and data from the port's personnel and responsible authorities. Unfortunately, there was only one smart meter installed on the port facilities and as a result, hourly data was available for only the 1/3 of the total energy consumption. The total energy consumption was calculated through some assumptions and the monthly tables regarding the other 2/3, which were helpful as well and helped the team to comprehend the exact operation of the port. Some statistical methods were used in order to forecast the energy demand in 2030, as presented in Figure 2. Specifically, following the principle of business as usual and the method of time series decomposition, it is predicted that the energy consumption will be increased by almost 1.5 times, booming to up to almost 1 GWh/y. Consequently, the need for renovation of the port techniques and technologies is obligatory and there is a high necessity to move towards Renewable Energy systems (RES) to produce energy.

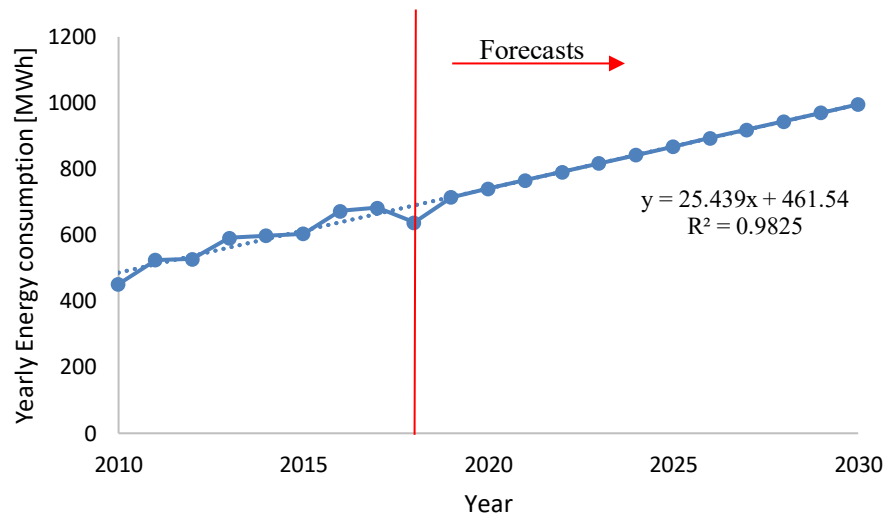


Figure 2. Port's yearly energy consumption from 2010 to 2030

Energy consumption of the port can be characterized as wasteful, taking into consideration the operations and services taking place there. So, it is inevitable to contain the current state and abrupt actions towards sustainability and decarbonization must be scheduled in order to repair the current over-dimensioning of the systems and improve its ecological footprint and diminish GHG emissions.

It is estimated that 20% of the world's power consumption is related to artificial lighting [18] and 1.3% to outdoor lighting [19]. In addition, ports' crucial energy demand is related to lighting energy demand and after thorough research and with the aid of the port's personnel, it was found out that more than 75% of port's energy consumption was related to lighting. Consequently, the energy efficiency of the lighting fixtures and energy management would lessen radically the corresponding energy consumption.

The most appropriate technology in order to change the old-fashioned lamps, is LED as it is the fourth generation of green lighting light source, has been widely used in a great variety of uses due to its low energy consumption, high photosynthetic efficiency, no pollution, long service life, etc. [20] Their efficiency today is 135 lm/W while on 2020, it is estimated to reach more than 200 lm/W and their lifespan is more than 50,000 h [21].

The simple replacement of all the existing lights with LED ones has been done in a previous study and the research team found out that the energy savings were almost 383 MWh/y which could be translated to 57,402 €/y and 258 t_nCO_{2eq}/y and a payback period [22] of 2.0 y. [23] For this research work, a totally new approach was selected in order to dimension the new lighting equipment and make it more efficient than the previous one.

So, the whole procedure of the new step-by-step methodology is depicted in Figure 3.

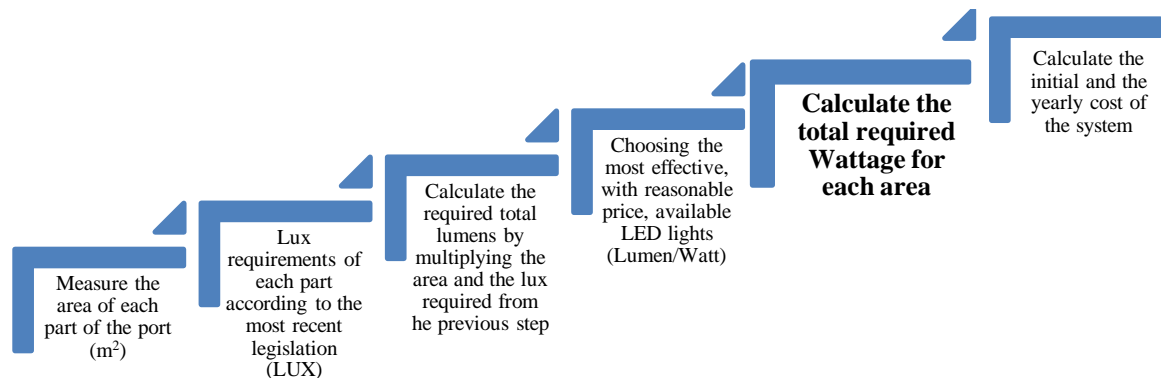


Figure 3. Dimensioning methodology for the new lighting equipment

This new lighting system can be enhanced using new smart systems to control and monitor it, in order to improve its efficiency and reduce the already-decreased energy consumption. As a result, this move will be a huge step forward for the port, demanding a great amount of money but will enhance both the appearance and the financial viability of port, by supplying it with new lights instead of the over-dimensioned ones that exist at the moment which will improve the total experience of someone into the port area. The significance of such an action can be extreme, as the port area offers a lot of parking slots and a respectable number of passengers get through it each year. Consequently, such an update of the port could be a great improvement as it may make the port more attractive.

Due to the rigorousness of the threat postured by anthropogenic climate change, which is mainly motivated by fossil fuel combustion, it is more and more acknowledged that societies have to convert the ways they produce and consume energy. [24] The exploitation of RES into the port infrastructure will not only enhance the ecological footprint and diminish the GHG emissions not only inside the port area but on the city of Rethymno, as well. It is a necessity towards a sustainable and feasible future of the city and will, additionally, enhance the environmental conditions and the appearance of the whole surrounding environment.

Taking into consideration all the aforementioned, an energy transition from fossil fuels to RES is a necessity for this specific port and its surrounding city and that's what the research team attempted to accomplish. The concept of converting a building, a neighbourhood, a community, a port or even a city into a nearly Zero Energy system, is based on the principles of sustainability, reliability, feasibility, and decarbonization. Such a prospect will improve the standards of living for people and make this world a safer and more pleasant -to live- place. Last but not least, the most environmentally friendly and sustainable solution is to create a 100% autonomous system, without the need of fossil fuels to operate in conditions that do not favor RES's energy production, and this can only be achieved by implementing energy storage technologies to such infrastructures, which are really expensive for the time being.

The main goal of this research work is to attempt to achieve the prospect of converting the Rethymno's port into an nZEP through both the modernization of several of its techniques and the implementation of RES. The most crucial aspect of this attempt is the harmonization with the most recent legislation and the decarbonization of the port. Superior emphasis was given to upgrade the lighting technology of the port and the implementation of Photovoltaic Systems into carports. To achieve such an intention, different solutions were studied so as to be in compliance with the features and structures of the old harbor and to serve the initial purpose. Such a task would be unable to be achieved if the cooperation of the municipality and harbour personnel, who provided all the required data and information, was missing.

3. Results

In order to convert the port to nZEP and afterward review and rate it, it was essential to split the research work into two parts. The first one, was about the lighting equipment and the total redesigning of the port's lights, as the current system is over-dimensioned and extremely energy-intensive. The second

step, after the optimal design of the lighting system, was to implement a RES to produce green energy and attempt to cover the total energy needs of the port through this system. In the following two sections, the two steps and the results of them are presented, in depth.

3.1 Lighting equipment

First of all, after identifying the share of energy consumption that corresponds to lightings, the first thing to do was to replace the old-fashioned equipment with a new one. The most appropriate lamps are the LED ones, as their efficiency, today is 140 lm/W while on 2020, it is estimated to reach more than 200 lm/W and their lifespan is more than 50,000 h. So, the initial step was to redesign the lighting system of the port and totally replace and renovate it. After splitting the port into 3 main districts, the area of each one was measured, the required lux (luminance) of each area was found from the EN12464-2 standard regarding the outdoor lighting of workplaces and the rest required data was calculated as seen in Table 2.

Table 2. Newly dimensioned lighting system proposed technical characteristics

	Area [m ²]	Lux based on stand- ards	Lumen	Lumen per W	Watt- age [W]	Energy Demand [kW]	Energy Consumption [MWh/y] ¹	Install- ation Cost k€/kW	Total Cost[€] ²
Marina	51,500	20	1,030,000	140	7,357	7.4	32.2	15	110,360
Commercial Venetian part Sof.	33,500	50	1,675,000	140	11,964	12.0	52.4	10	119,643
Venizelou St.	11,500	20	230,000	140	1,643	1.6	7.2	1	1,642.9
Total						21.0	91.8		231,643

After this upgrade, the port is going to save almost 450 MWh and 67,500 €/y and 312 tnCO_{2eq}/y³ will be avoided and the payback period of this investment will be 3.45 y, which is significant taking in mind the lifespan of this specific technology. In addition, if the forecast regarding energy consumption in 2030 is taken into consideration and the assumption that the lighting will still be the 75% of the port's total energy consumption, the energy savings will be 655 MWh and almost 99,000 €/y and 445 tnCO_{2eq}/y will be saved.

A scenario was examined regarding implementing a smart technique for the operation hours of the lighting system. Specifically, the reduction of their power to half for the first and the last two hours of operation was examined, where there is still luminance due to the sun and the results were surprisingly well, as an additional of 12 MWh and 2,000 € will be saved each year and the payback period of the investment will be reduced to 2.84 y (If the installation costs of the controlling systems is taken into consideration, this is increased to 2.95 y).

3.2 Photovoltaic systems

Attempting to fulfil the total energy needs of the port by using “green energy”, and using only a RES technology, it was certain that the most appropriate technology was this of the PV systems as they are noiseless, the impact on the environment is relatively low and the technical and potential problems that may occur, are not great if everything is set up following the instructions [25].

At this case, it is of high importance to not disturb the residents, as the port facilities are inside the residential area of Rethymno and the proposed structures are not too big to disturb the visibility of the area but also they will enhance the total attraction of it. So, three parking lots of the port were selected in order to build carports and install the PV systems in their roofs and one charger of Electric Vehicles (EV) with two charging slots in each of them. This will not only provide green energy to the port

¹ For the calculation of the consumed energy, 12 operation hours per day for 365 days were considered.

² An average energy cost of 0.15€/kWh was taken into consideration.

³ The CO_{2eq} factor for Crete equals to 0.67377kg CO₂/kWh

facilities but also will provide protection from the sunlight for the cars and make the port's parking more attractive. Furthermore, there are only a few similar installations in Greece, making this investment, relatively pioneering for a port in Crete.

The three parking locations are depicted into Figure 4, where each PV system, implemented into the carport, is installed, using Helioscope software, for both the current state (a) and for the 2030's forecasted situation (b). Each location is selected wisely in compliance with the safety regulations and in order to not affect the natural view and the systems are dimensioned using the energy needs of each case.



Figure 4. PV systems installations in the two case studies, (a) current state case, (b) 2030 forecast case

The first system is comprised of 882 modules of a total 264.4 kWp installed power and the second one by 1,192 modules of a total 357.6 kWp installed power. The first system produces 366.4 MWh/y of green energy and the second one 495.5 MWh/y, covering the port's energy demand in both cases.

The energy demand of the port in the first case after the lighting renovation and the EV chargers installation is 343.5 MWh/y and in the second case, 493.1 MWh/y. Consequently, the green energy produced is enough to cover the energy needs of the port infrastructure and a small portion of it can be distributed to the city of Rethymno, as well. As for the payback period of the investment, it is difficult to get an exact price per square meter for the carports, so after a market review, it was assumed that an average price of 100 €/m², is the ideal one for such constructions.

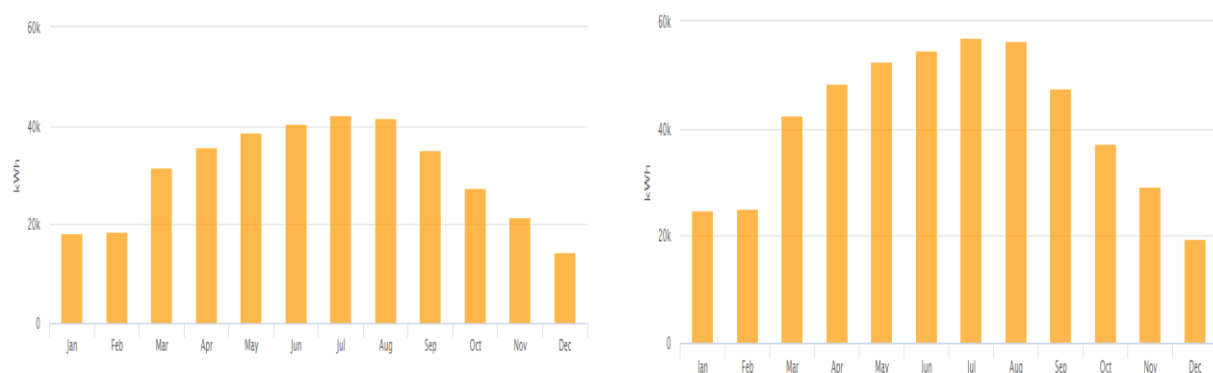


Figure 5. PV systems energy production for each case, (a) current state case, (b) 2030 forecast case

So, using all the required data, the payback period for the first case is 9.4 y and for the second one is 9.7 y. It is important to mention that the incomings from the upgrade of the parking area are not calculated, which will contribute a lot in reducing the payback period of such an investment as it will make the parking more attractive as the cars will be protected and EV's charging will have a low cost.

On the other hand, indicatively, it is mentioned that if no carports were proposed and the PV systems were installed in roofs and other unused spaces of the port, the payback periods for the PV systems and

the EV chargers would be 3.9 and 3.8 y, respectively. The monthly energy production of each system is depicted in Figure 5.

3.3 nearly Zero Energy Ports are a reality!

The initial port consumption for the first case was 638.5 MWh/y, after renovating the lighting equipment with LED ones and redesigning the system, the port consumption decreased to 177.4 MWh/y and after the implementation of the three EV chargers, the final port energy consumption increased to 343.5 MWh/y. On the other hand, the PV systems that are proposed to be installed will cost a great amount of money⁴ as an initial investment but will cover the energy needs of the port in both cases (Table 3).

Table 3. Energy and financial details of the two cases

	#1 Current state	#2 2030 forecast
Initial Energy consumption [MWh/y]	638.5	996.0
Final Energy consumption [MWh/y]	343.5 (177.4 ⁵)	493.1 (327.1 ⁵)
Payback period of the investment [y]	9.4 (3.8 ⁶)	9.7 (3.9 ⁶)
Energy Produced [MWh/y]	366.4	495.5
Money Savings [€/y]	54,960	74,325
CO ₂ avoidance [tnCO _{2eq} /y]	246.9	333.9

So, the attempt of converting the port to nZEP succeeded in both cases, proving that it is both feasible and can be characterized as a profitable investment, financially speaking. Every proposed solution is in compliance with the Greek legislation regarding PV installations and the net metering system and all these can be enhanced if the port is considered as an energy community[26], so the maximum allowed the energy that could be produced there, will be exceptionally increased.

4. Conclusions and Recommendations

The port sector seems to face a lot of barriers in order to harmonize with recent legislation and in the process of upgrading their old-fashioned techniques and technologies to new ones. Consequently, their effort to comply with recent legislation regarding environmental issues is increasing year-by-year. Besides, the currently used techniques and technologies are old-fashioned due to the fact that ports, since now, had a primary goal to ensure their safety as the main priority. So, with recent legislation regarding sustainable and green energy, there is a huge opportunity, for upgrades and renovations and, at last, enhance port infrastructures' sustainability and capabilities.

The case study of Rethymno port proved that there is high potential into converting ports, especially medium ones, to nZEP, as their energy consumption is mainly caused by old-fashioned technologies and techniques and there is high capability of installing RES. In the two examined cases, it was proved that the installation of the PV systems required was in compliance with the most recent legislation and the prospect of converting the port into nZEP was feasible and realistic.

The energy savings are important due to both the reduction of the energy costs and the avoidance of CO_{2eq}, which enhances both the elimination of GHG emissions and the decarbonization not only inside the ports area but on the surrounding city, as well. This paper improves the current state-of-the-art as it proposes the conversion of an old-fashioned port to a modern one which can be a landmark for the city of Rethymno, with just two interventions.

The question is, how much energy savings will be if smart energy management systems (EMS) and techniques are adopted and an energy storage system, such as a hydrogen one, will be implemented in order to make the port really autonomous and diminish its energy demand from fossil fuels to zero.

⁴ For the PV systems, all the required costs are calculated (Grid-connection, installation, supply of systems).

⁵ Without EV chargers

⁶ Without carports

Consequently, this research work showed that there are various things that have to be promoted in order to enhance the viability and the sustainability of ports, like the RES propulsion into ports, the stricter penalties if no greenification actions are taking place and more importantly to give inspiration and motivation to port authorities through rewards and subsidy of “greenifying” actions.

Last but not least, the most useful recommendations for further research, are:

- The examination of implementing EMS and smart techniques, such as automation into the port
- The examination of implementing other types of RES technologies, such as wind, wave, tidal and biomass
- The replacement of all old-fashioned technologies in every port’s service, with new-generation ones, such as new HVAC systems, new more efficient pumps
- The implementation of an energy storage system like a hydrogen one
- Ports should be considered as energy communities

As a remark, nZEP will not boost only the tourism sector to diminish operational expenses and to enhance competitiveness and sustainability but local authorities in the same way, as well.

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